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MINI HYDRAULICS

Meeting the challenges of miniaturization

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Power density refers to how much power a system or assembly transmits within a prescribed envelope. High power density is among the most useful characteristics of hydraulic systems. Pressurized fluid contained within hydraulic cylinders can move loads weighing thousands of pounds quickly and accurately — all with an almost effortless pivot of a control lever or joystick.

When components become miniaturized, high power density becomes more difficult to main-tain, even if systems operate at higher pressures. If hydraulic systems did not operate at high pressure, they would lose their high-power-density advantage, and a competitive technology — such as an electromechanical system — may be used instead. However, higher pressures generally require stronger, heavier-duty components. This necessitates thicker walls and piston rods, which works against the goal of miniaturization.

Smaller size: bigger challenges

Cutting a component's size does not necessarily reduce friction by a proportional amount. So as components become smaller, higher pressures and flows are required to generate the same power per unit of volume as with the larger component. For example, seal friction usually increases as a result of higher operating pressure. This means doubling pressure to a cylinder will not quite double its thrust. On a more basic level, decreasing the diameter of a circular piston reduces surface area exponentially. However, only a linear reduction in circumference occurs. And because piston seal contact area is a function of circumference, decreasing the size of a cylinder increases seal friction in proportion to thrust.

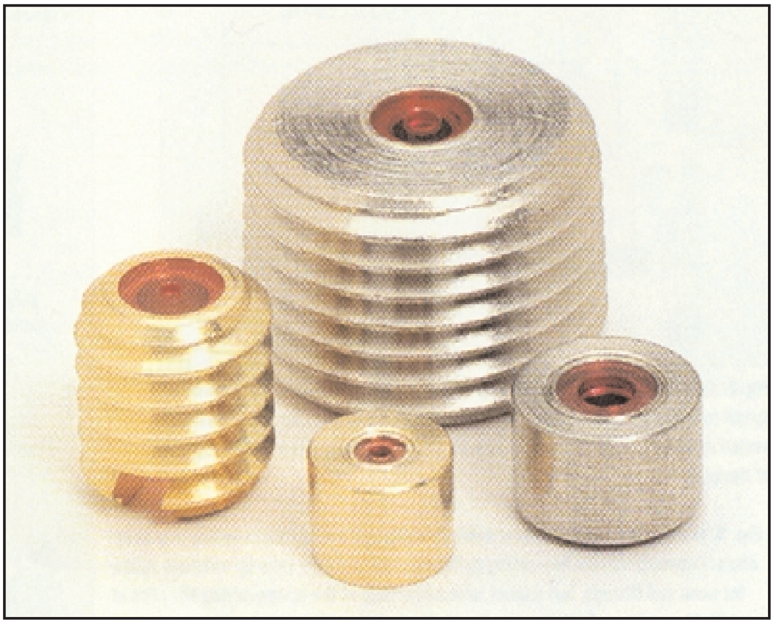
Internal leakage also contributes to power loss. If the same clearances are used for a miniature cylinder as in a larger cylinder, more flow is lost to internal leakage in the miniature cylinder. This internal leakage can degrade not only actuator speed but thrust as well. Consequently, miniature components must be manufactured with very tight tolerances to maintain high operating efficiency and performance. But manufacturing components with tighter tolerances increases cost. Moreover, the reduced clearances of these components requires more intensive filtration to keep contamination particles from clogging up, jamming, or damaging miniature components.

Hydraulic systems that must operate in extremely small spaces often demand more performance per pound than heavy-duty systems many times their size.

Higher performance without higher cost

The solution to these challenges would seem to be simple: miniature components will cost more money. This is true in many cases, especially when components must be custom designed. These special cases may involve:

- making components of the highest strength materials available
- employing the most sophisticated manufacturing techniques



Bird Precision

Fig.1. Close control of tight tolerances is essential to miniature components, because a deviation of 0.1301 in. allows 5% error for a 0.020-in. ID orifice. Rut if the orifice has an ID of only 0.005 in., that same 0.001 in deviation creates an error of 20%.

- machining components to tolerances in the hundredths of thousandths of an inch, and
- specifying the highest performance filtration systems available.

However, most designers try to avoid specifying custom-designed components for the simple reason of economy. Fortunately, a number of manufacturers incorporate innovative techniques to provide the high performance required by miniature systems without sending costs through the roof.

Orifices provide consistent precision

One basic way of keeping costs down in any industry is to make components in large quantities. The problem is, not all manufacturing processes lend themselves to high-volume production. A flow orifice, Figure 1, must be carefully machined to a precise diameter, be concentric with the channel in which it is mounted, and exhibit a high degree of roundness. Moreover, it should be made of a hard, wear-resistant material to ensure long life.

Typically, these orifices regulate flow of hydraulic fluid in cylinders, valves, and circuit branches. To provide a predictable, precise flow, a sharp-edged orifice must exhibit a consistent discharge coefficient (C_d) from one component to the next. Therefore, the opening of each orifice must be of the same size, shape, and location from one piece to the next.

Paul Baillio, of Bird Precision, Waltham, Mass., explains that conventional drilling, electro discharge machining (EDM), or laser drilling can produce flaws when used in orifice production. Drill wobble, tool marks, ragged edges, poor surface finish and eccentricity may degrade G of the orifice. More importantly, it can cause orifices to exhibit a range of C_ds instead of one consistent C_d.

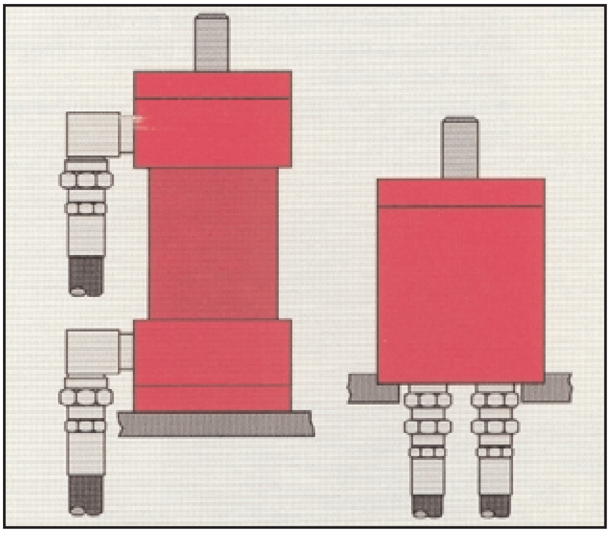
A poor choice of materials of construction further complicates orifice performance, continues Baillio. Even if a steel or brass orifice is manufactured consistently with high precision, these materials can quickly wear, again affecting their C_d. This is especially important with the higher operating pressures often associated with miniature hydraulic systems, because wear accelerates as pressure increases.

Baillio suggests a wire lapping method as an alternative to conventional orifice machining. This method involves cutting a pilot hole in an orifice blank, then threading a wire through the pilot hole. Introducing a diamond slurry as the wire is pulled through the hole produces orifices with tolerance variations of 0.0002 in. with extremely sharp edges, and a mirror-like surface finish of 2 μ-in. In additional to producing very precise orifices, the process is also economical, because thousands of orifices are threaded and lapped at a time.

Using a synthetic ruby material ensures high wear resistance even at pressures to 20,000, explains Baillio. The synthetic nature of the ruby makes the orifices economical, and mounting them in a variety of standard configurations makes them economical for a wide range of applications. Their consistency from one orifice to another means that they don't have to be installed as pairs to provide balanced performance.

Mountings and configuration

Sometimes taking advantage of unconventional mountings and configurations is all that's needed to substantially reduce the envelope of components. For example, bottom-ported cylinders, Figure 2, eliminate having to locate hoses



Mack Corp.

Fig.2. Conventional double-acting cylinders, left, consume substantial space to accommodate fitting and hose at both head and cap ends. Bottom-ported cylinders, right, reduce the envelope by locating inlet and outlet ports at the cap end.

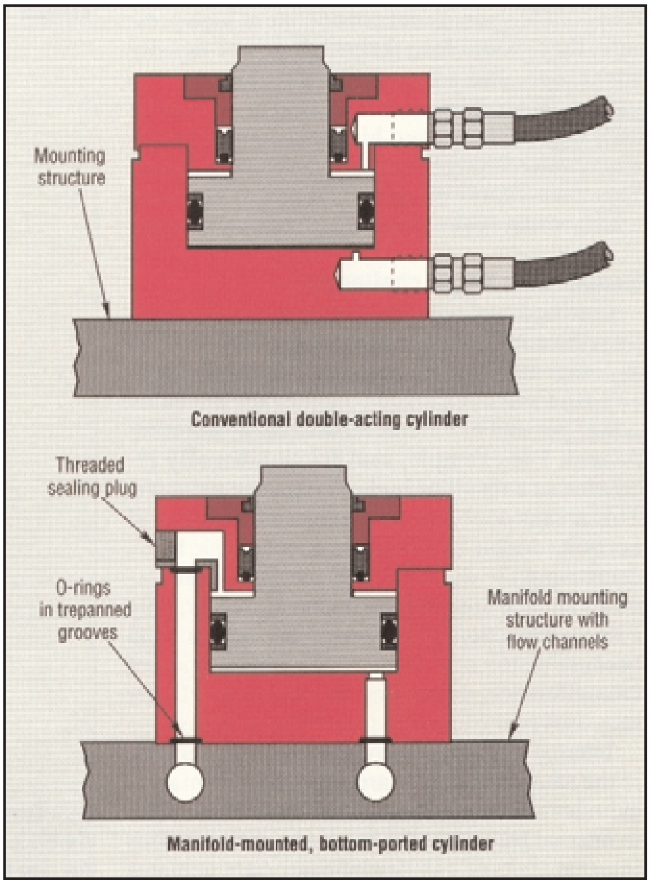


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Fig. 3. Tooling jigs often use manifolds to route hydraulic fluid to valves and actuators. Conventional double-acting cylinders, top, not only take up valuable space for hose and fittings, but cannot take advantage of the space-saving benefits of manifold mounting. Bottom-ported cylinders, on the other hand, can be manufactured for mounting directly into a manifold. If warranted by the application, the cylinder can even be mounted into a recessed counterbore in the manifold, so that only the cylinder rod extends from the manifold.

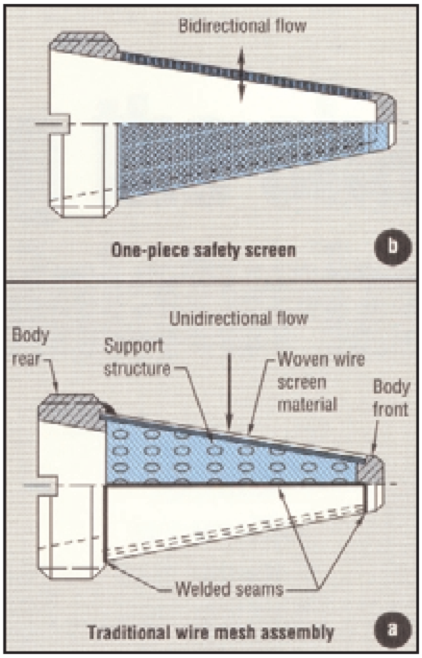
and fittings near the cylinder barrel. In this configuration, fluid entering one port flows directly into the cylinder's cap end. Fluid entering the other port passes through an internal channel and enters the head end of the cylinder. The cylinder itself is not any smaller than a conventional one, but relocating hoses and fittings to the cap end of the cylinder frees up space at the "business end" of the cylinder.

Taking this concept a step further, bottom ported-cylinders can even be mounted in a manifold, Figure 3. Cartridge mounting completely eliminates the need for hose, tubing, and fittings to be connected directly to the cylinder. This technique mirrors the same advantages enjoyed by cartridge valves: economy, reduced potential for leakage, compact design, and a simpler, neater package.

Protecting critical components

As mentioned above, filtration is especially important in miniature hydraulic systems to prevent solid contaminants from blocking the typically narrow passageways and tight clearances. Even if fine filtration is implemented, contaminants can still be introduced downstream of filters. Left unchecked, these particles can lodge into narrow passageways or tight clearances, causing system malfunctions or damage.

A popular method of protecting systems and components from such malfunctions is installing a filter screen, Figure 4a, at the inlet port of critical components. Sometimes called a last-chance filter, these screens are designed to trap particles that exceed the size of holes in the screen.



The Lee Co.

Fig. 4. Conventional filter screen, *A*, is an assembly of components, which adds cost to the structure. Moreover, support grid protects the screen from rupturing in only one direction of flow. One-piece filter screen machined from bar stock, *B*, is self-supporting, which prevents collapse in either direction, even when full pressure is applied to a completely clogged screen.

Besides being expensive to manufacture, these screens typically can fail once they become completely clogged. This is because when clogged, differential pressure across the screen can equal system pressure. Consequently, applying pressure of several hundred psi can cause the screen to deform or even rupture. In an attempt to prevent this, conventional screens have a backup structure to support the screen if it deforms from a high differential pressure.

Conventional screens, however, suffer from several shortcomings, according to Walter Tischbein, of the Lee Co., Westbrook, Conn. First, they are expensive to manufacture by virtue of their being an assembly of components. Second, the backup structure supports the screen for only one direction of flow. In addition, the support structure reduces the contamination carrying capacity of the screen.

Tischbein describes a cost-effective alternative, Figure 4b, that offers better performance as well. Machining a safety screen from a solid piece of stainless steel bar stock eliminates the expense of manufacturing a multi-component assembly. Furthermore, making the screen thicker and drilling the holes into the screen eliminates the need for a support structure. This is because the screen itself is strong enough to withstand a pressure differential equal to full system pressure. HP

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